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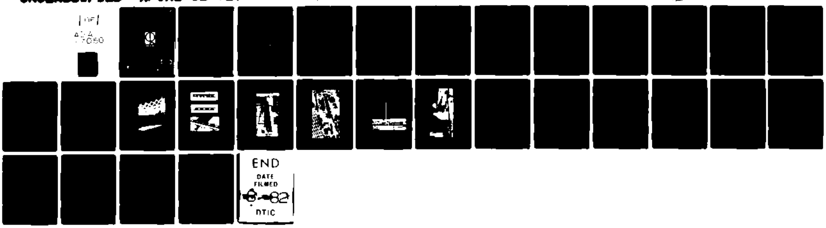

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Research Note

Broadside and Scanned Beams from Arrays of Variable Spaced Elements Proximity Coupled to a Two-Wire Line

G. R. FORBES
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Scanning $\pm 50^{\circ}$ from broadside, a new type of "stretch" antenna array consists of dipole elements proximity-coupled to an open two-wire line. The dipoles are supported at a fixed height above the transmission line and the spacing changed from $\lambda/2$ to λ.

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Abstract

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Contents

Acknowledgments

Mr. Francis J. Zucker, Chief, Waves and Circuits Branch of the Electromagnetic Radiation Laboratory, AFCRL, suggested the scanning method for the back quadrant and contributed the Appendix. The machine work was done by Michael D'Adderio, William Mathison, and Fred Byam.

Illustrations

Broadside and Scanned Beams from Arrays of Variably Spaced Elements Proximity-Coupled to a Two-Wire Line

1. INTRODUCTION

In June 1957, C. J. Sletten and G. R. Forbes of the Electromagnetic Radiation Laboratory published a report[1] on a new type of VHF-UHF antenna. The radiating elements described in this report were proximity-coupled to a two-wire transmission line. The degree of coupling depended strongly on the angle which the elements (dipoles) made with the axis of the transmission line, maximum coupling occurring at an angle of approximately 20°.

The new array is made up of elements that are supported at a fixed height such that the center-to-center element spacing can be varied from $\lambda/2$ to λ along the axis of the two-wire line. This principle allows scanning to be done over large angular regions from broadside by simple transport of the radiators relative to the feeding line.

Research has continued on this general type of proximity-coupled array, both in-house and on a contract basis. The general objective of this research was to develop an inexpensive, practical method of scanning large fixed arrays. A number of mechanical and electromechanical methods of scanning were tested. Most of these methods and their characteristics will be discussed.

(Received for publication 17 August 1962)

2 DESCRIPTION

The first scanning method investigated was a multisection pantograph linkage network that was mounted between and parallel to the two-wire line. Each dipole was attached to the uppermost movable joint of the section providing a uniform spacing between dipoles at a fixed height above the two-wire line (Fig. 1). By extending or contracting the linkage system, the dipole spacing could be varied from $\lambda/2$ to λ. The dipole axes are coplanar and set at a prescribed angle with the axis of the two-wire line. The pantographic linkage network is driven by a linear worm screw powered by an AC reversible motor. This method proved adequate for small arrays of less than 20 ft. Long worm screws, close tolerance, friction and drive power limitations make this system unsatisfactory for larger arrays. Figure 2 shows an eight-element full scale model for 600 MC.

In another method, the dipole carriages were connected to one another with springs (Figs. 3 and 4). It was found that the springs had to be carefully matched so that each one was under the same tension. Starting and moving friction caused non-uniform motion leading to relatively large accumulative errors. In addition, this scheme required a large drive force. Although the system is simple and inexpensive, the errors of positioning and drive forces required make it unsatisfactory for large arrays.

Another method of transporting the elements using a long logarithmic screw was investigated by the A. G. A. Corp.[2] The elements were attached to collars mounted on the screw. Rotating the screw caused the element spacing to change properly. Small working models were built but the cost of machining a long screw was excessive. Also, lengths of 20 ft or more were impractical. Therefore, this scheme could not be used in large arrays.

In another method investigated, the carriages were connected to one another by gum rubber tubes that acted as springs. Although the drive requirements were not as severe as those with springs, careful adjustment of the tension in the tubes was required . Again, repetition of positioning was poor because of carriage friction.

It was thought that if the carriages were eliminated, and the dipoles mounted directly on a long 8 in.wide gum rubber belt, friction problems could be greatly reduced. The rubber belt was secured at one end of the array and rolled up on a drum at the other end. The elements were printed on small bakelite strips cemented to the belt. By rolling the belt up on the

drum, the elements could be made to move properly. However, as the spacing became larger and the tension in the belt increased, the edges of the belt curled up (or down), tilting the dipoles in a random manner so that they were no longer coplaner. For this reason, this scheme was abandoned.

The most satisfactory mechanical scanning method investigated used a long pure gum rubber $\frac{1}{2}$ in.tubing. The tubing was attached at one end of the array and run down the center just below the two-wire line to the other end, where it was rolled onto a drum. The drum was driven by a reversible motor. The carriages that supported the dipoles were made of two round teflon wheels that rolled between the two-wire line. Each carriage was carefully made to minimize friction effects. The wheels were held together by a small section of plexiglass on which the dipole was mounted. A pin that extended down from the plexiglass pierced the rubber tubing and formed the mechanical connection between the carriage and the tubing. The pins had to be placed in the tubing while it was under maximum tension to achieve proper initial element spacing. This scheme is inexpensive and simple, yet it yields sufficiently high positioning accuracies to be used in large arrays. Figures 5 and 6 show a complete picture of the entire array.

An electro-mechanical method of scanning was set up also in which the antenna was scanned by changing the element spacing by discrete values; in the full size model the increment chosen was $\lambda/50$. Each element was mounted on its own motor-driven carriage along with a small stepping switch (Fig. 7). These carriages moved along a rail on which index points were located at intervals of $\lambda/50$ (Fig 8). Each time the carriage passed over an index point, the stepping switch on the carriage was advanced by one count. Each carriage was identical except that the stepping switch was adjusted to remove the power from the drive motor at a different number of counts. In this way, the first carriage moved $\lambda/50$, the second $\lambda/25$, etc. By repeating the above process, the element spacing may be adjusted to any integral number of increments between $\lambda/2$ and λ.

The antenna scanning is accomplished through a control panel and is completely automatic. The operator need only select the desired element spacing on the control panel (Fig. 9). The carriages then move in the proper direction until the correct spacing is obtained. The antenna stops and lights a lamp on the control panel to show that the scan has been completed. Then antenna may also be calibrated. When a calibrate switch is depressed, all elements move to their fully contracted position and all step-

ping switches are returned to zero. Again a lamp is lighted to show that calibration has been completed. Another feature included is interlocks which prevent a scan or calibrate complete indications until all elements are in their proper positions. Provision has been made for scanning the antenna in the "manual mode". In this mode, the control panel changes the spacing by only one increment.

Because of the nature of this scanning system, it has a very high inherent accuracy depending only on the positions of the index points on the rail. The errors in spacing can be held quite easily to less than 1/10 in. The system is very reliable and simple, requiring no adjustment once set up and is not affected by extremes of temperature. However, it would need to be protected from snow and rain. It is fully automatic and gives a continuous indication of its position (spacing) and beam angle. The control panel need not be changed to be used with any number of elements and automatically indicated malfunctions in the system.

3 EXPERIMENTAL RESULTS OF AN EIGHT-ELEMENT ARRAY

Figure 6 is a photograph of the model designed to operate a 600 Mcps with $\lambda/2$ dipole spacing. In the E-plane elevation pattern (Fig. 10) (broadside to the array), the half-power beamwidth is about 13° with side-lobes of -13 db, the same as would be predicted for any uniformly illuminated array. Such arrays with illumination of any desired taper would be easy to design since conductances (g) ranging from zero to $1.0 g/G_o$ are attainable, where G_o is the reciprocal of the characteristic impedance of the line. *Cross-polarization on such arrays* would be small because maximum coupling is obtained at about 20° of rotation and most elements would be rotated at much less. Mutual coupling is small between dipole elements thus oriented.

By spacing the dipoles $\lambda/2$ apart and making the coupling angle alternately + 5° and -5°, there results a broadside pattern, whose beamwidth is 13°. If, instead of alternating the coupling angle of successive dipoles, the coupling angle is maintained for all dipoles at + 5°, a broadside beam of 9° results for a one wave-length spacing. For the same dipole orientation, a decrease in the dipole spacing toward $\lambda/2$ provides a 50° scanning movement of the main beam and a broadening of this beam to ~ 18° (Fig. 11). The beam movement is a rotation toward the feed end of the two-wire line. If the line is fed from its other end instead, the direction of beam rotation is reversed. Under these conditions an expected scan angle of ± 50° is possible. Likewise, scanning can be achieved by spacing the dipoles a full

wave-length apart and alternating the dipole coupling angle with 180° phase reversal. The beamwidth now becomes approximately 6°. This is to be expected, inasmuch, as the antenna aperture has been doubled. However, the main beam has now shifted direction to 28° from broadside and another beam of equal magnitude appears an equal number of degrees on the other side of the broadside beam position (Fig.12). Ambiguity is avoided by limiting the scan angle to approximately 20°. This array can be made to scan still further by placing every other dipole on alternate sides of the two-wire line and stretching them from $\lambda/4$ to $\lambda/2$. There is no physical contact between dipoles as their spacing is varied. The radiation patterns corresponding to the above conditions are shown in Figure 13.

4 CONCLUSIONS

a. A continuously scanning proximity-coupled array has been designed and its pattern characteristics examined.

b. The array has good scan capabilities and narrow beamwidth.

c. The array has a limited bandwidth.

d. Because of the low cost of fabrication, arrays of this type should find application in the fields of satellite tracking and radio astronomy in the VHF and UHF bands.

e. It is of importance to note that the phase velocity on the feeding transmission line is less than the velocity of light and the radiators used are not directive along the axis of the array. First-order diffraction lobes are suppressed when the dipoles are not phase-reversed (rods are parallel and not zig-zag). This permits a stretch array to be scanned over wider angles with nonphased-reversed elements than with 180° phase reversal between elements.

Figure 1. A Close-up View of a Single Dipole Element and a Section of the Pantograpn Device which Allows the Dipoles to Move Linearly.

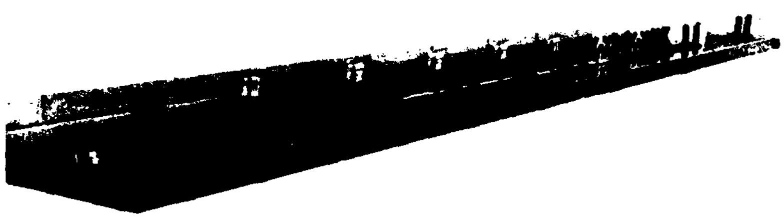

Figure 2. Eight-element Array Showing the Pantograph Device which Allows the Dipoles to Move Linearly Varying their Spacing from $\lambda/2$ to λ.

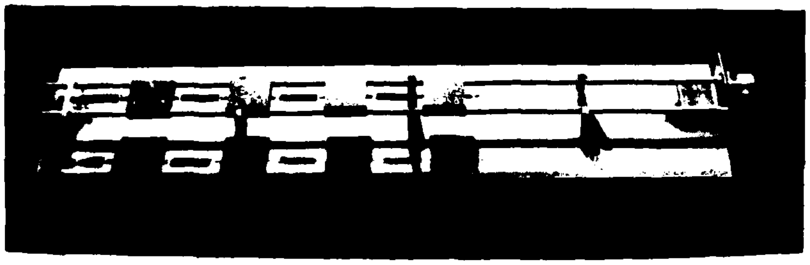

Figure 3. A Close-up View of the Wire Springs between Dipole Carriages in a Relax Position.

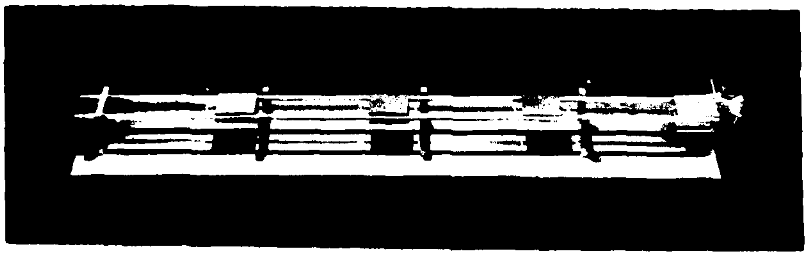

Figure 4. The Same Case as Figure 3 only the Wire Springs between Dipole Carriages are now Stretched Out to their Required Limits.

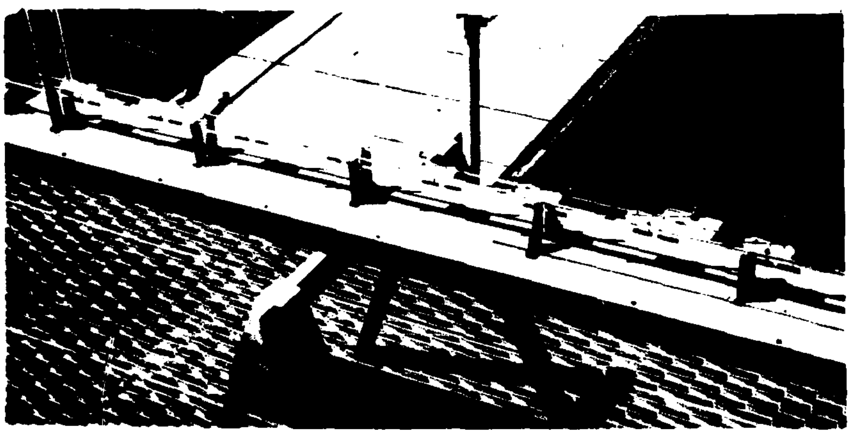

Figure 5. Eight-element Array Shows a Close-up View of Dipole Carriages and the $\frac{1}{2}$" Rubber Tubing which Control the Spacing of the Dipole.

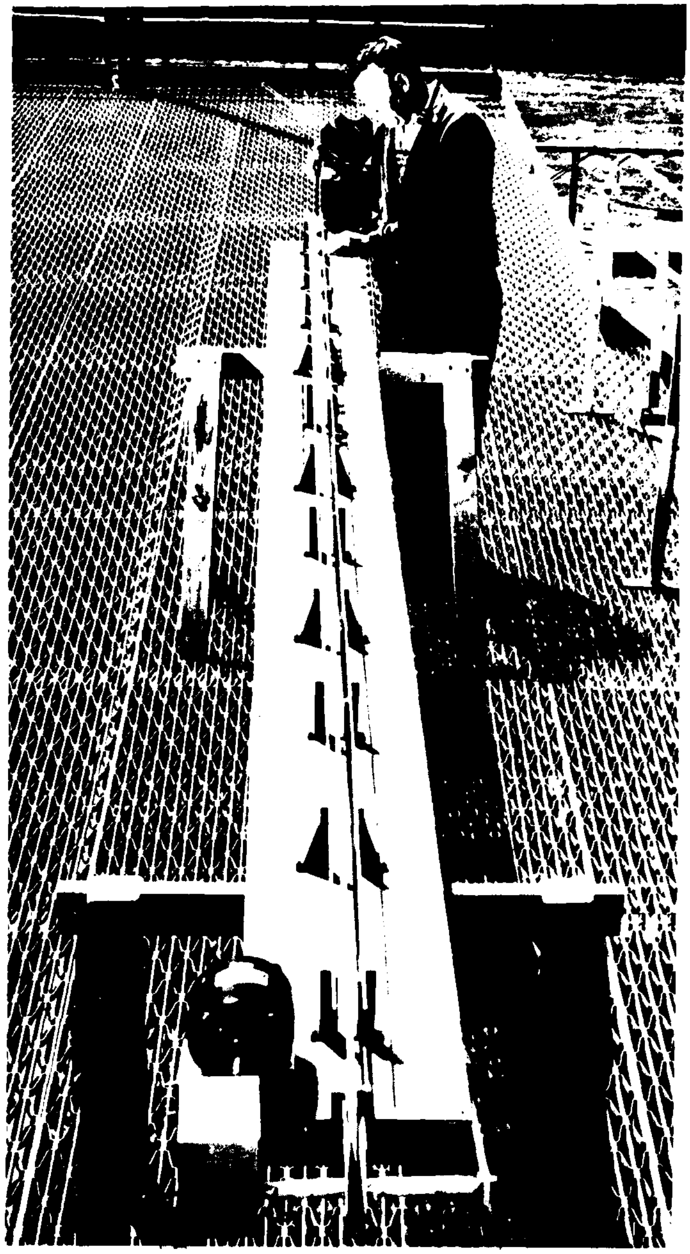

Figure 6. Complete Picture of Entire Array Shows Reversible Motor, Dipoles, and Rubber Tubing Down the Center of Two-Wire Line.

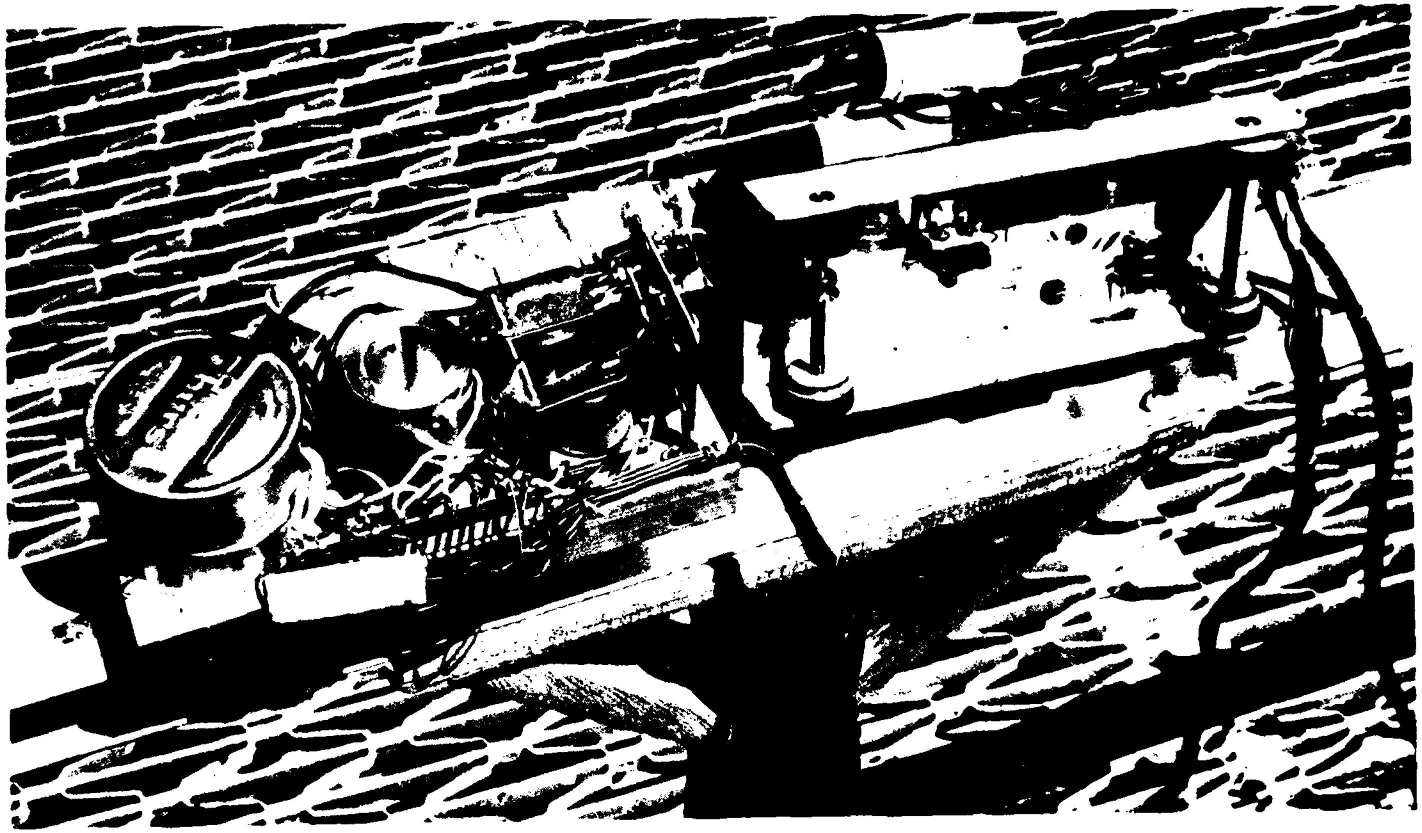

Figure 7. Close-up View Showing Motor, Stepping Switch and Microswitches.

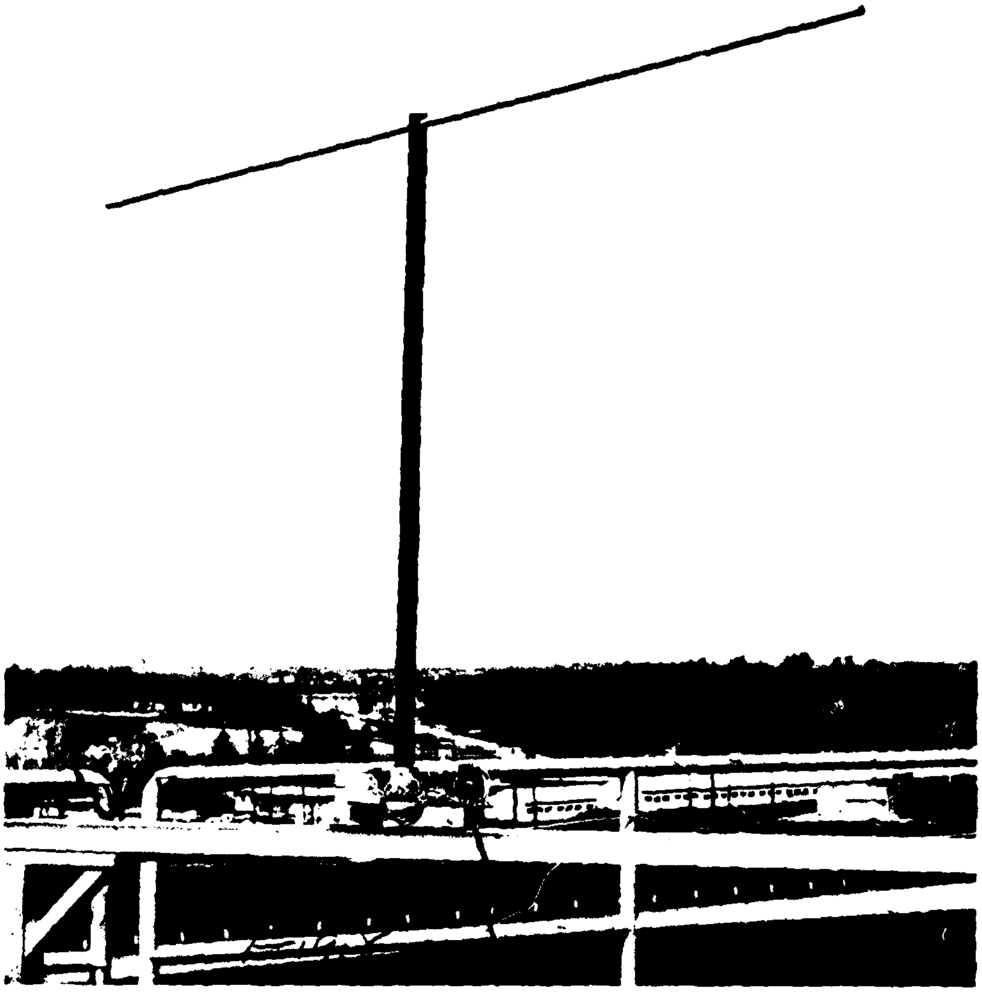

Figure 8. View of Carriage, Showing Dipole Mounting, Moving on Rail.

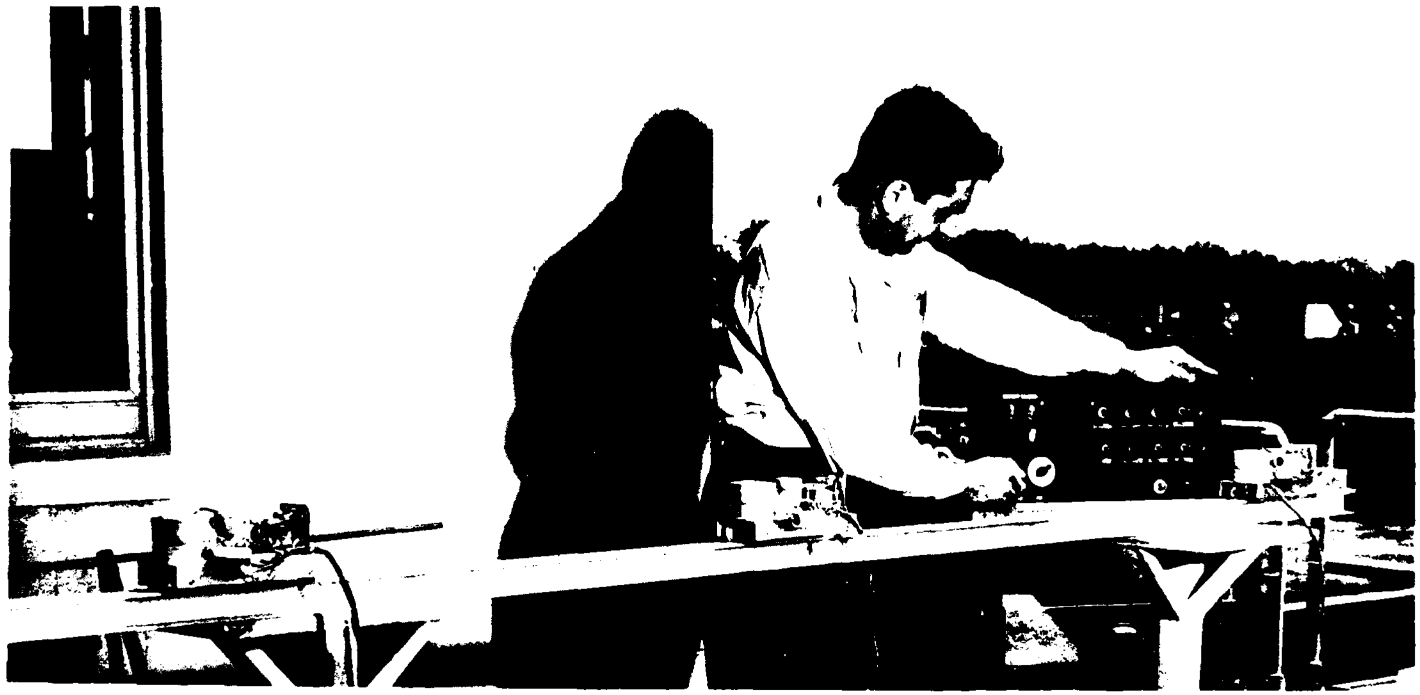

Figure 9. View of Rail, Carriages, and Control Panel

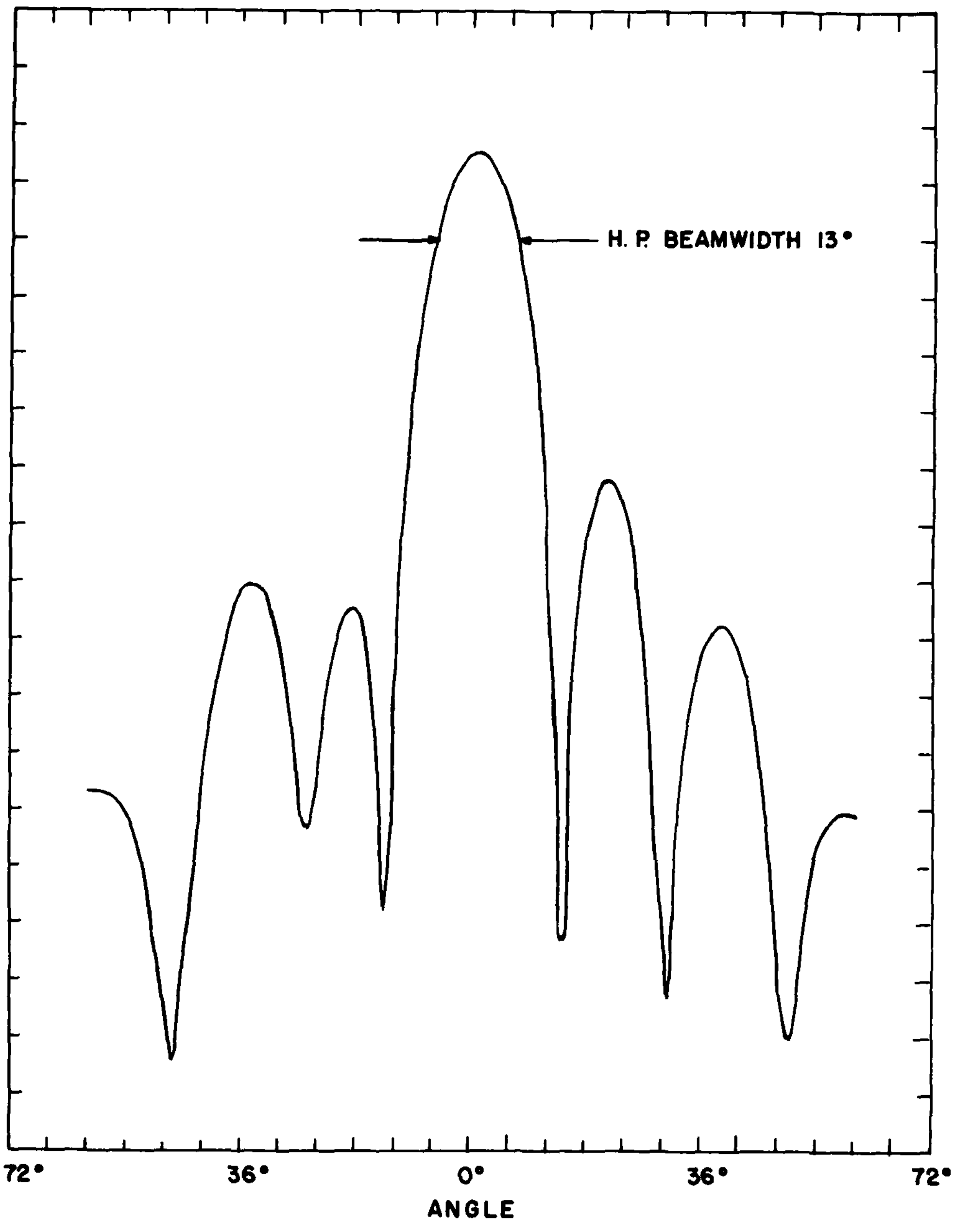

Figure 10. E-plane Elevation Pattern of Eight-element Antenna Array (f = 600 Mcps) with $\lambda/2$ Spacing and the Dipoles Zig-Zag.

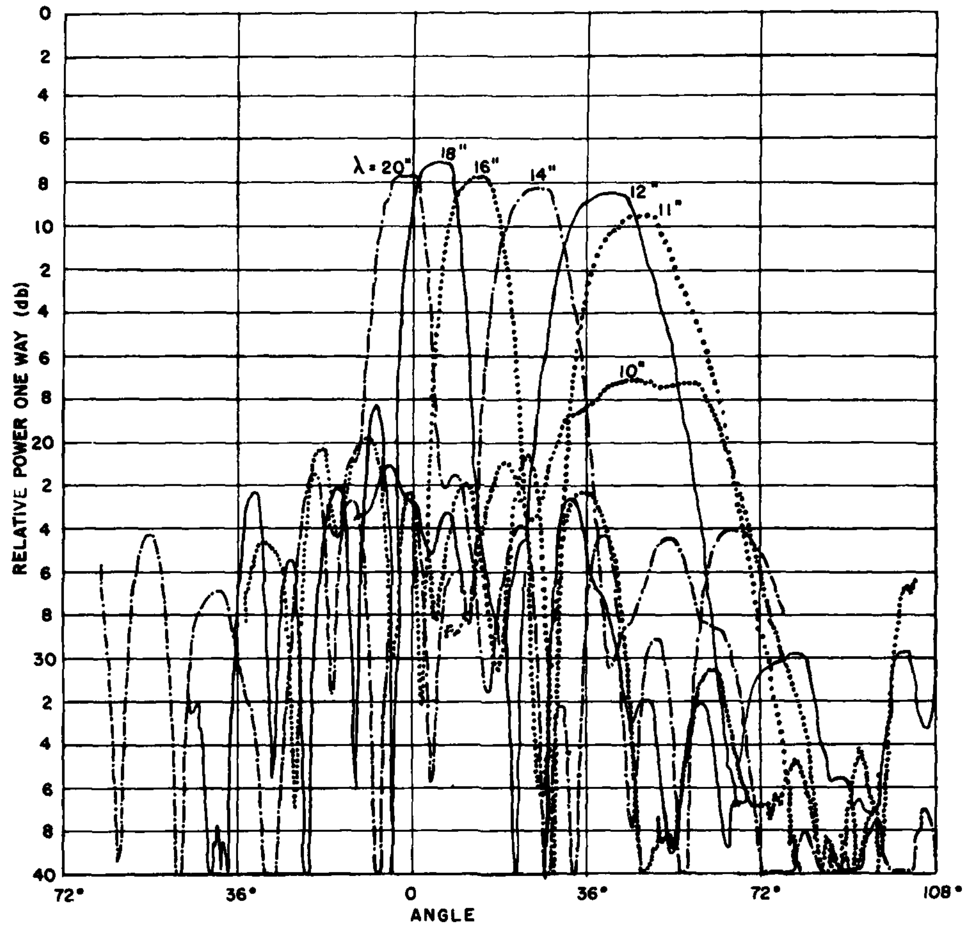

Figure 11. E-plane Radiation Patterns of Eight-Element Array Showing the Amount of Scanning in Degrees When You Vary the Dipole from λ/2 to λ. This is Without the 180° phase reversal in the Dipoles.

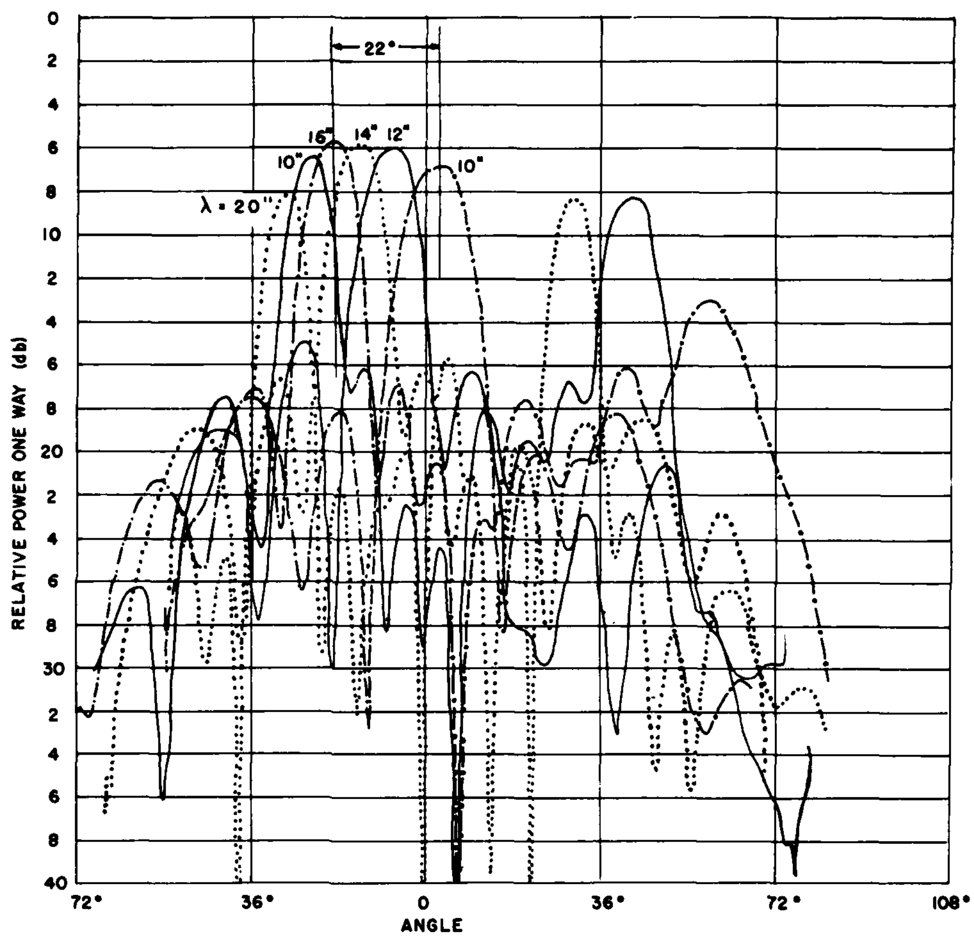

Figure 12. E-plane Radiation Patterns of Eight-Element Array Showing the Amount of Scanning in Degrees When You Vary the Dipole Spacing from $\lambda/2$ to λ. This is with the 180° Phase Reversal in the Dipoles.

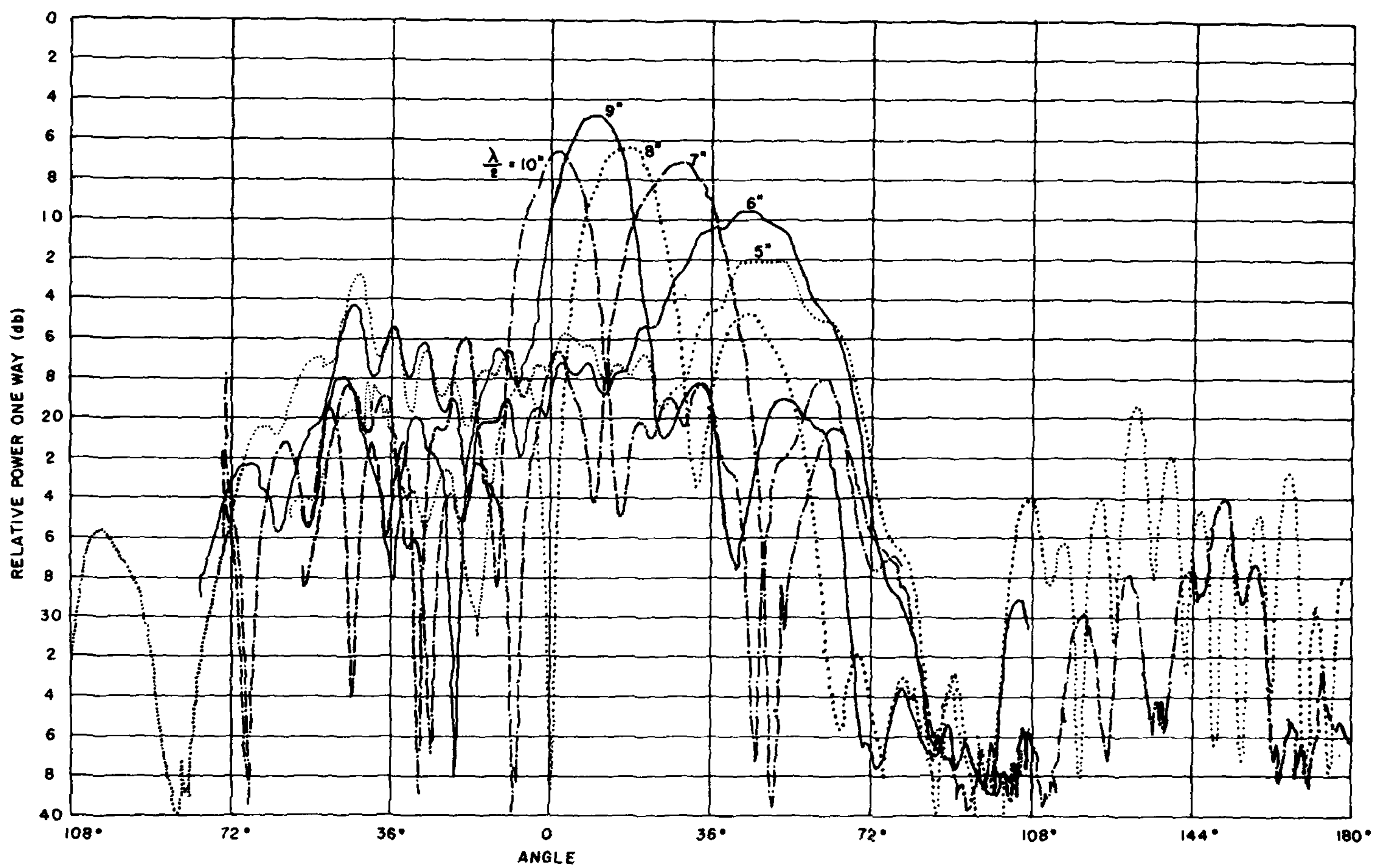

Figure 13. E-plane Radiation Patterns of *Eight-Element* Array Showing the Amount of Scanning in Degrees When You Vary the Dipole Spacing from $\lambda/2$ to $\lambda/4$. Every Other Dipole is Placed on the Other Side of the Two-Wire Line.

References

1. C. J. Sletten and G. R. Forbes, "A New Antenna Radiator for VHF-UHF Communications", AFCRC-TR-57-114, AF Cambridge Research Center, Bedford, Mass., June 1957.

2. Aero Geo Astro Corp., "Research on Scanning Techniques for Large Flat Communication Antenna Arrays", Final Report, 8 Dec 1960, *AFCRL-TR-60-364, Contract AF19(604)-5217, Aero Geo Astro Corp.*, Alexandria, Virginia.

Appendix

Main Lobe Direction on Arrays Fed by a Two-Wire Line

The direction of the main lobe produced by a traveling-wave-excited array of discrete elements is given by elementary array theory: with Θ the angle off broadside (positive toward endfire), λ_g the wave-length along the line, and (d) the interelement spacing,

$$\sin \Theta = \lambda/\lambda_g - (\lambda/d)m \quad (m = 0, \pm 1, \pm 2 \ldots .) \tag{1}$$

for an array of identical elements, and

$$\sin \Theta = \lambda/\lambda_g - (\lambda/d)(n + \tfrac{1}{2}) \quad (n = 0, + 1 + 2 \ldots .) \tag{2}$$

for an array of alternately phase-reversed elements. On a two-wire line, $\lambda/\lambda_g = 1$ (loading by the elements actually produces a ratio slightly larger than 1, but the approximation is good enough for our present purpose). We now have

$$\sin \Theta = 1 - (\lambda/d)m \ , \tag{3}$$

and

$$\sin \Theta = 1 - (\lambda/d)(n + \tfrac{1}{2}) \ . \tag{4}$$

The range of Θ values permitted by these equations is restricted by the need to suppress secondary beams. The direction of the secondary beams nearest to the principal lobe is found by replacing m by m + 1 and m - 1 in Eq. (3) and n by n + 1 and n - 1 in Eq. (4). Let us examine the lowest orders of m and n in turn:

a. With m = 0, Eq. (3) has as its only solution

$$\Theta_{m = 0} = 90° \tag{5}$$

(endfire). Substitution of m = 1 in Eq. (3) shows that a principal side-lobe will arise in the visible region <u>unless</u>

$$\lambda/d \geq 2, \quad \text{or} \quad d/\lambda \leq \tfrac{1}{2} \tag{6}$$

The equality sign holds provided the element pattern has a null at $\Theta = -90°$ (backfire), where the principal side-lobe first arises as d increases from zero. Substitution of m = -1 shows that the other principal side-lobe is always in the imaginary part of the pattern space; the restriction shown in Eq. (6) is thus the only one to be imposed when pure endfire operation is desired.

An example of the m = 0 type of operation is the endfire array of transverse dipoles. We can, according to Eq. (6), let $d = \lambda/2$ provided the ele-

ment has a backfire null. Let each "element" consist of two dipoles spaced $\lambda/4$ apart. Since these are fed in space and time quadrature, their pattern is a cardioid, which has the required null at $\Theta = -90°$. Thus, an array of transverse dipoles spaced $\lambda/4$ apart produces a good endfire pattern.

b. With m = 1, Eq. (3) reads

$$\sin \Theta_{m=1} = 1 - \lambda/d \quad . \tag{7}$$

Substitution of m = 2 in Eq. (3) shows that a principal side-lobe will arise in the visible region <u>unless</u>

$$2\,\lambda/d \geq 2 \quad \text{or} \quad d/\lambda \leq 1 \quad . \tag{8}$$

The equality sign again holds provided the element pattern has a null at $\Theta = -90°$(backfire), where the principal side-lobe first arises as d increases from zero. Substitution of m = 0 gives Eq. (5); *therefore, this* lobe can only be suppressed provided the element pattern has also a null at $\Theta = 90°$ (endfire). Substitution of Eq. (8) in Eq. (7) restricts the range of $\Theta_{m=1}$ to

$$0° \geq \Theta_{m=1} \geq (-90°) \quad .$$

An example of m = 1 type of operation is the array of longitudinal dipoles when the dipoles are all oriented in the same sense with respect to the array axis. Experimentally, the beam could be scanned from 0° to only 50°, beyond which the pattern deteriorated. This is most likely so because the endfire and backfire element nulls are not sharp. Therefore, the restriction shown in Eq. (8) ought to have been made more severe.

c. With n = 0, Eq. (4) reads

$$\sin \Theta_{n=0} = 1 - \lambda/2d. \tag{9}$$

Substitution of n = 1 in Eq. (4) shows that a principal side-lobe will arise in the visible region <u>unless</u>

$$3\lambda/2d \geq 2, \quad \text{or} \quad d/\lambda \leq \tfrac{3}{4} \quad . \tag{10}$$

The equality sign holds, as in the case of Eq. (6) and (8), provided the element pattern has a backfire null. Substitution of n = -1 gives only imaginary angles, and thus imposes no further restriction.

The range of $\Theta_{n=0}$ is restricted by substitution of Eq. (10) in Eq. (9) to lie within

$$20° \leq \Theta_{n=0} \leq (-90°) ;$$

it is further restricted by the physical impossibility of spacing alternately phase-reversed dipoles more closely than $\lambda/2$, so that

$$20° \leq \Theta_{n=0} \leq 0° \quad .$$

An example of n = 0 type of operation is the array of longitudinal dipoles, when the dipoles are alternately oriented in the opposite sense with respect to the array axis.

d. Values of m and n other than those discussed are not of interest because either they produce a main beam at an imaginary angle, or else at a real angle. In the latter case, the m = 0 and 1, or n = 0 main beams are simultaneously present and cannot be suppressed.

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